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The role of references in the astronomical discourse

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Abstract. We have counted the number of references in 1179 papers published in *Astronomy and Astrophysics* over twenty years. The number of references has increased by 60% between 1975 and 1995, reflecting the increase (by the same amount) of the literature which must be cited, and of the number of pages per paper. There are 1.5 times more references in predominantly observational fields than in others. References are used 1.65 times in the text, and there is no trend with time or field. They appear mostly in the introduction (30%) and in the main body of the paper (60%), but papers in predominantly observational fields tend to use less references in the introduction and more in the main body than papers in the other fields. Most references (62%) serve to support a result, and tend to be of theoretical nature. Astronomers are a very conformist bunch, as there are no trends with nationality, and references to conflicting evidence are kept at about 8%. The analysis of a series of papers by de Vaucouleurs on the Hubble constant shows how a controversial subject affects the use of references.

Key words: Not yet given.

1. Introduction

References have often been used by sociologists of science for measuring the output, impact and quality of scientific research. The number and frequency of references in astronomical papers have been extensively studied, for example for evaluating the impact of research by various groups of astronomers (Jaschek 1992, Trimble 1985, 1993ab, Peterson 1987), the productivity of telescopes (Abt 1980, 1985), the life-time of papers (Abt 1981, Peterson 1988), the effect of funding on the quality of research (Abt 1984), the flows of information between astronomy and neighboring fields (Davoust et al. 1993).

But little attention has been paid, at least in astronomy, to the way references are used in the scientific discourse inside the paper. They play an essential role in supporting the authors' claim that the presented research is correct and valuable. Thus exposing the method by which astronomers try to reach this goal is very useful, as it provides a manual of referencing style that one should follow in order to be published.

In this paper, after presenting our sample (Sect. 2), we analyze how and why the number of references varies with time and scientific field (Sect. 3, 4), we then study the distribution of references in the body of the papers (Sect. 5), determine the different purposes for which they are used in the text (Sect. 6), and analyze how a controversial subject affects their use (Sect. 7). The conclusion provides a manual of referencing style for astronomers.

2. The sample of papers and references

We chose *Astronomy and Astrophysics* (hereafter A&A) as the source of references. This journal is the medium in which most European astronomers publish, and one of the most distinguished journals in its domain. It covers most fields of astronomy, and has the advantage that the papers are sorted into 8 or 9 fields in its table of contents.

Although A&A started publication in 1969, we decided to count references from 1975, considering that, by that date, the journal had found its cruising speed. We sampled references every five years, a small enough interval to determine the time dependence of the reference patterns. Four volumes (400 to 600 pages each) of A&A per year was enough to get good statistics, with small fluctuations (see Table 1). In 1995, we only used three volumes (which contain 800 pages each).

The number of fields increased over the years, reflecting the expansion of research in most subjects. In 1975, fields 7 and 8 were only one field. In 1980, field 5 was broken into two subfields (stellar structure and evolution; stellar atmospheres), and in 1984, fields 6 and 7 were both divided into two subfields. To save ourselves some work, we sorted by hand the papers of fields 7 and 8 in 1975, but did not consider the two subfields of 5, 6 and 7 as separate. This is justified because of the close links between the subfields. The field numbers are identified in Table 1.

We counted by hand all the references at the end of all papers of the first four volumes of 1975, 1980, 1985, 1990, and of the first three volumes of 1995 of A&A. We excluded letters and research notes from the counts, because these shorter papers have a different purpose than more complete papers, and thus presumably a different style and rhetorical method. We also excluded the *Supplement Series* of the journal, for similar reasons.

3. Evolution of the number of references per paper

The number of references per paper has increased in all fields over the years. The rate of increase is of the order of 60% over 20 years. The fact that the world literature has also increased by 60% over that period of time (estimated by the

number of entries in the semi-annual issues of *Astronomy and Astrophysics Abstracts*) provides an obvious explanation for this trend : there are simply more papers to cite.

The number of pages (normalized to 1000-word pages) per paper has also increased at almost the same rate (55%), from 6.6 to 10.2 pages. The tendency for the number of pages per paper to increase is in fact a general one; Trimble (1984) gives the following figures for the rate of page increase between 1950 and 1980-83 : mathematics (77%), physics (27%), chemistry (93%), and astronomy (82%). Returning to our subject, the net result is that the number of references per normalized page in A&A has remained fairly constant at 3.4$\pm$ 0.2. In other words, the absolute number of references, not their density, has increased over the years. There are more published results to cite and discuss when writing a paper, if one wants to be comprehensive, and this requires more space in the journal. The interesting implication here is that the number of *relevant* references has increased in proportion with the total number of references, and it is somewhat reassuring to find an indication that the inflation in papers does not result from an excess of useless ones.

Abt (1987) has found a tight correlation between the number of references nr and paper length pl (normalized to 1000-word pages) of astronomical papers published in 1986, such that $nr = 9.9 + 2.18pl$. This relation predicts the correct number (slightly overestimated, but within one unit) of references per paper in A&A for all years except for 1995, where it is 5 references short.

These trends are shown on Fig. 1, where minor differences in slope of the three curves may be explained by editorial constraints and statistical fluctuations. The number of references counted by Vin (1995) in 6 astronomical journals (A&A, A&AS, ApJ, ApJS, MNRAS and AJ) in 1980-93 and by Abt (1987) in 8 astronomical journals in 1986 are also plotted (as crosses), for comparison. They fall very close to the solid line, which means that our sampling of A&A is representative of the world astronomical literature.

Fig. 1. Evolution of the number of references per paper in A&A (dotted line), of papers per year in *Astronomy and Astrophysics Abstracts* (in thousands, solid line) and of normalized pages per paper in A&A (dashed line). The number of references per paper in 6 or 8 astronomy journals is also given for a few years (crosses)

Field 9 (physical & chemical processes) stands out in this respect, because the number of references has been decreasing since 1985 (see Fig. 2). We checked that this is not a statistical fluctuation, as the tendency is even more marked when including more papers per year. This may be due to the fact that this is a borderline field of astronomy; astronomers perhaps cannot keep up with the information explosion in neighboring fields.

4. Patterns of reference in the different fields

While the number of references per paper increases with time, it is not uniform over all fields in a given year. There are two categories of fields, those with a high rate of citation (stars, galactic and extragalactic astronomy, interstellar matter), with an average of 42 references/paper in 1995, and those with a low rate of citation (the Sun, celestial mechanics, instruments, planetary systems, physical & chemical processes), with an average of 27 references/paper in 1995. Figure 2 shows the number of references per paper in the different fields at the five epochs, and the actual numbers are given in Table 1, where the last line is the mean weighted by the number of papers in each field.

Fig. 2. Distribution of the number of references per paper in each field in 1975 (dotted line), 1980 (dashed line), 1985 (longdashed line), 1990 (dot-dashed line), 1995 (dot-longdashed line), and of the proportion of observational papers over all epochs (in percent, solid line). The field numbers are identified in Table 1

We tested two possible assumptions for explaining this trend.

We first checked whether the difference could be due to the internal dynamics of the fields, if there are more references per paper in the fields which contain more papers. The numbers of papers published in the different fields have been counted by Davoust & Schmadel (1987, their Table VI) in the period 1969-1985. Using their data, we found that there is no correlation between the number of published papers and the number of cited references per paper in the different fields. Take for example fields 1 to 4, which have a low rate of citations; if our assumption is correct, there should be the same (low) number of published papers in these four fields. But there are at least twice as many papers over 27 years in field 2 than in 1 and in 4 than in 3. Conversely, there should be the same (high) number of published papers in fields 5 and 8; but there are in fact over twice as many in 5 than in 8. This trend is also apparent in the last column of our Table 1, although with larger fluctuations, since we have been taking small samples.

This lack of correlation suggests that papers do not necessarily cite references in their own field, provided that the

Table 1. Number of references per paper and per field in A&A over 20 years. The last column is the total number of papers

	Subject	1975	1980	1985	1990	1995	n
1	The Sun	22.16	20.88	24.21	26.68	30.04	98
2	Planetary Systems	18.83	25.70	28.27	28.47	33.29	66
3	Celestial Mechanics & Astrometry	10.83	11.33	16.67	19.00	26.38	36
4	Instruments & Data Processing	8.57	7.70	15.18	14.40	21.50	51
5	Stars	26.81	25.91	28.53	33.22	38.75	352
6	Cosmology & Extragalactic Astronomy	25.94	27.02	35.73	34.80	43.96	227
7	Galactic Structure & Dynamics	30.07	29.65	36.96	29.00	43.88	106
8	Interstellar Medium	29.32	34.17	36.08	34.04	39.90	143
9	Physical & Chemical Processes	16.50	18.75	25.69	23.00	22.20	100
	Mean	24.07	24.65	30.15	30.45	37.20	

proportion of meaningful papers (the ones that deserve to be cited) is the same in all fields. An interesting implication, which still has to be checked, is that some fields, 8 for example, must be strongly related to other fields (supplying information to, or drawing it from, other fields), since they apparently cite more papers than there are papers to cite in their own field. They are thus more multidisciplinary than others, which in our opinion is a quality.

We then checked a second possibility, which turned out to be the correct one, namely that the difference in citation rate was due to the type of research, theoretical or observational, predominant in the different fields. We sorted all the papers of our sample into one of three categories, theory, observations, or theory-and-observations, and redistributed the numbers of the last category evenly between the two others.

Theoretical papers outnumber observational ones by 2 to 1, and the ratio remains constant (0.64$\pm$0.02) over 20 years. But there is a definite trend with field (see Fig. 2), as there are less references per paper in the 3 fields with a very strong majority of theoretical papers (celestial mechanics, instruments & data processing, physical & chemical processes). A possible explanation is that theoretical papers only cite theoretical ones, whereas observational ones, which must provide interpretation or modeling to be in the main journal, cite both types of papers. Another explanation is that observational papers benefit from several large data bases which provide immediate access to most references related to a given celestial object (we are indebted to Carlos Jaschek for providing this remark).

The correlation between field and rate of citation is not as sharp as the one between field and type (theoretical vs observational), because in all papers, irrespective of the field, the references are mostly to theoretical papers (rather than to observations, methodology or for other purposes; see Sect. 6).

The number of references per paper has also been studied in other fields of science. Vin (1995) gives the following numbers for the year 1993 : computational sciences (22.2), mathematics (22.5), physics (26.3), chemistry (39.5), biochemistry and molecular biology (44.1). But these numbers are not directly comparable to those in astronomy, because the average length of papers may not be the same in the different fields; Abt (1987) notices that, in 1986, astronomy papers were 1.8 times longer than physics papers.

We found no trends related to the nationality of the authors. Abt (1987) reaches a similar result; he notes that there is no difference between American astronomical journals and others (namely MNRAS, A&A and PASJ) in their average number of references per paper of same length. His conclusion is that the scientific methods are the same and that authors tend to copy the styles of the papers that they read. We may add that the norm that astronomers have to conform to in order to have their papers accepted for publication is rather strict and enforced by referees from all over the world. The fact that the overwhelming majority of papers are in English may also contribute to this uniformity.

5. Distribution of the references in the text

After identifying variations in the number of references per paper with time and field, we now analyze how the references are used in the paper itself.

References are used on the average 1.65$\pm$0.13 times in the text, and there is no trend with time or field. In other words, the typical reference is not used repeatedly in the discourse, but only once or twice. The case where up to 3 or 4 references are frequently used in the text does occur, but relatively rarely (20 to 30% of the time). In other words, authors do not tend to overemphasize the relations of their paper to the literature.

The references are used in increasing proportion in the abstract (1.1%), the conclusion (8.2%), the introduction (30.2%), and the main body of the paper (60.5%). These rates reflect to some extent the proportion of text in the different sections, except for the introduction, which is obviously an important part of the paper, where the scientific context is traditionally presented, with an appropriate number of references.

There are slight differences with fields, as there are relatively more references (9 points in %) in the main body (and conversely relatively fewer references in the introduction) of papers in predominantly observational field than in that of papers belonging to more theoretical fields. This simply means that the excess of references which characterizes predominantly observational fields (see Sect. 4) is cited in the course of the discussion, rather than in the introduction. Since this excess is made up of references to observations (see Sect. 6), this also implies that observations are cited in the discussion rather than in the introduction.

Table 2. Frequency of references (in percent) according to purpose in the text, in the 9 fields of astronomy. The last three lines are the 3 types of (supporting and conflicting) information

	Purpose \ Field	1	2	3	4	5	6	7	8	9	mean
1	Scientific, historical context	9.16	10.61	19.24	13.10	10.07	9.49	5.20	2.91	13.84	10.4
2	Similar research	11.06	7.52	19.70	19.05	13.49	15.51	13.69	2.68	6.59	12.1
3	Supporting information	67.57	76.55	40.79	52.38	57.93	57.25	65.53	72.48	67.99	62.1
4	Conflicting information	7.83	2.56	5.31	0.00	14.47	10.73	5.67	21.47	8.61	8.5
5	Definition	1.79	1.80	2.08	4.76	1.52	0.00	3.03	0.46	0.00	1.7
6	Source of data, instruments	2.60	0.95	12.88	10.71	2.53	7.02	6.87	0.00	2.97	5.2
A	Theory	51.31	62.34	51.59	75.00	46.94	47.19	46.07	45.18	52.56	53.1
B	Observations	32.20	27.19	22.07	20.45	33.85	42.87	39.77	50.31	32.69	33.5
C	Methodology	16.49	10.46	26.34	4.55	19.20	9.93	14.16	4.51	14.75	13.4

Celestial mechanics stands out in this respect, as there are three times more references in its abstracts than in those of other fields. As the abstract is the most visible part of a paper, this probably reflects the strong need of authors in celestial mechanics to emphasize the relevance of their work. Another striking characteristic of this field is that the references are often to unusually old papers. These should perhaps be considered specific features of academic subjects.

6. The purpose of references in the astronomical discourse

Our main interest is to investigate for what purpose references are cited in a given paper. To this end, we adopted a simple classification of the references into 6 purposes, which are listed in Table 2. The distinction between purpose 2 and 3 is sometimes subtle; similar research is generally cited in the introduction, without any judgment on its contents. We further subdivided purpose 3 and 4 (after merging them together) into reference to theoretical, observational or methodological information. The distinction between theoretical and methodological reference is not always obvious; the latter is in principle a reference to theoretical means (an equation, a model) for reaching one's goal. The references to observational means (instruments, data) to be used in the discourse are classified as purpose 6.

Taking the present paper as an example, we would classify the references as follows. In the introduction, all references are 1. In Sect. 3, the first occurrence of Abt (1987) is 3C, because we did not parametrize our correlation, otherwise it would be 3A; Trimble (1984), Vin (1995) and the second occurrence of Abt (1987) are 3B. In Sect. 4, Davoust & Schmadel (1987) is 6; Vin (1995) is 2, since we cannot compare the quoted numbers to ours, otherwise it would be 3B; the first occurrence of Abt (1987) is 6, since we implicitly use the quoted number of pages to argue that no comparison is possible in general, otherwise it would be 3B; the second occurrence of Abt (1987) is 3B. In Sect. 7, all references are 6.

We thus classified all the references in the papers of 1995 in our sample. The results are displayed in Table 2 and Fig. 3, and discussed next.

— Most references (62% on the average, or 65% excluding celestial mechanics) are to information in support of the results of the paper. This is not an unexpected result, our only merit is to quantify the effect. Celestial mechanics stands out with a low 40%, because the context is twice as important as in other fields.

— All the other types of references are around or below 10%.

— References to conflicting information fluctuate around 8%. There is of course a bias here, since a piece of research with a majority of conflicting evidence would be very difficult to publish. We believe that a large number of citations to conflicting evidence is a sign of good health, and that the lack of controversies is evidence for a static field, with no major breakthrough in progress; in this respect, fields 5 and 8 rate very positively. A remarkable fact is that field 8 (the interstellar medium) has very high rates of supporting *and* conflicting references, but, since there are very few references for other purposes, the absolute numbers are not unusually large. Field 8 still strikes us as an unusual one, whose referencing pattern should perhaps be investigated further.

— References to context and to similar research only amount to 22%. Because they are usually confined to the introduction, we expected their relative number to be of the order of 30%, which is the proportion of references cited in the introduction (see Sect. 5). The reason for this discrepancy is that the scientific debate often already starts before the end of the introduction, with references (generally) in support of the project.

We now turn to the relative rates of theoretical, observational and methodological references.

— The proportion of references to theoretical papers is fairly constant, with an average value of 53%. Fields 2 (62%) and 4 (75%) are the most deviant ones.

— The proportion of references to observational papers depends on the field in roughly the same way as the absolute number of references (see Fig. 1), which in turn depends on the type (observational or theoretical) of the field. If we take for example fields 5 to 8, which are predominantly observational, they produce 1.56 times more references than the other fields (see Sect. 4), and these references are 1.54 times more observational than in the other fields. In other words, there is a good correlation between the types of the citing and cited papers.

Fig. 3. Relative importance of the different purposes of references in the 9 fields of astronomy. Context (longdashed line), similar research (dotted line), supporting information (dashed line), conflicting information (solid line), definition (dot-dashed line), source of data or instruments (dot-longdashed line)

7. A case study : de Vaucouleurs on the Hubble constant

Gérard de Vaucouleurs (1918-1995) is one of the most remarkable astronomers of the second half of this century; he was highly productive, with 208 papers published between 1969 and 1985 (Davoust & Schmadel 1987), and highly cited, with 686 citations in 1982 (ranking second only to Chandrasekhar; Trimble, private communication; Trimble 1985). Among other noteworthy achievements, he played a fundamental role in the debate on the Hubble constant. These enviable qualities led us to select his series of 8 papers on the Hubble constant which appeared in the *Astrophysical Journal* between 1977 and 1993 (see de Vaucouleurs 1993, de Vaucouleurs & Bollinger 1979 and references therein) as a basis for a case study on rhetorical skill. Readers may object that the journal is not A&A, but this series of papers is simply unique. Who else would have written a homogeneous set of 8 papers or more in the past twenty years on one of the major contemporary issues in astronomy?

The total number of references in this series of papers is slightly above average (50±15 per paper), and their frequency of appearance in the text is well above average. Paper VIII, which appeared 14 years after the first seven, and is de Vaucouleurs' final word on the value of the Hubble constant, contains 72 different references, but they appear 466 times in the text (a frequency of 6.5 per reference). Excluding this final paper, the frequency is 2.0 per reference (compared to 1.65 on the average in A&A).

Keeping in mind that these papers are essentially a debate between de Vaucouleurs' determination of the Hubble constant and that of Sandage & Tamman (hereafter ST), we find that autocitations and references to ST appear with the same high frequency in the text (2.5, excluding paper VIII). In this last compilation paper, references to other papers have a higher frequency (8.7) than autocitations (5.2) and references to ST (4.0). Excluding autocitations, references to ST, and paper VIII, we find that the frequency of references in the text is normal (1.7). It is thus the debate with ST which raises that frequency. It is interesting to note that, in the reference lists, the number of autocitations rises monotonically from 5 in paper I to 32 in paper VII, while the number of references to ST remains quite constant, between 5 and 7. The author thus increasingly drums his other papers to the fore as the debate progresses.

The division of the discourse into 8 papers is the main cause for the unusual distribution of references in the text. The introduction is always very short and contains a very small proportion of references (6%), as most of them are used to structure the debate in the text (72%) and in the appendices (17.2%). Most papers have appendices, this is part of de Vaucouleurs's style which often relies on them as well as on footnotes; the discourse thus gains in conciseness and clarity or, conversely, the paper thus gains in precision and completeness. But in the present series, the number of appendices and footnotes (respectively 2 and 6 per paper on the average) is unusually high.

The intense (but courteous) debate modifies the proportions of references for different purposes. Only 40% of the references are to supporting information (including autocitations) compared to 62.1% on average, because conflicting information (15% instead of 8.5) and sources of data (25% instead of 5.2%) are more cited than usual. The author is obviously in ennemy territory, and draws more heavily on data to make up for friendly forces.

Data can be cited, but they can also be displayed in figures and tables. The number of figures increases progressively in the series, indicating more frequent recourse to visual display of information as the discussion proceeds, a wise strategy since figures are generally easier to perceive than numbers. There are also more tables in the second half of the series than in the first half, but no striking progression.

Finally, leaving the approach of scientometrics, the reader cannot but be awed at the talent with which the author leads him through the intricacies of the scientific debate, keeping him in suspense by only revealing the adopted value of the Hubble constant in paper VII.

8. Conclusion

The statistical analysis of the number and distribution of references in the text of 1179 papers sampled from A&A over 20 years provides a manual of referencing style for astronomers.

The number of references per paper has steadily increased over the years, in pace with the increase in the number of papers published worldwide, and with the consequent increase in the number of pages per paper. One striking exception is the number of references in the field of physical and chemical processes, which has been decreasing since 1985. Astronomers are expected to keep up with the inflation in astronomical literature at the expense of that in neigboring fields, and to cite it accordingly.

But the number of references per 1000-word page remains constant (3.4±0.2 references/page), as well as the number of times a reference is cited in a paper (1.65 times on the average). The number of references may increase with time, but they should be cited with moderation. No more than 60% of the references should be used to support the claims of the paper, and, for the sake of credibility, about 10% of the references should provide conflicting evidence.

The number of references per paper depends on the type (predominantly theoretical or observational) of the field. Authors may use 1.5 times more references if their paper belongs to the latter type of field.

The introduction of the paper plays a special role, with a large number of references (30.2% in relative numbers) compared to its size. One third of them should provide information for (and, once in ten times, against) the specific project of the paper.

There is no trend in referencing pattern with the nationality of the authors. Conformity is the rule.

The analysis of de Vaucouleurs's series of papers on the Hubble constant shows that, in papers at research fronts, more space than average should be given to data and conflicting arguments. Authors may then appeal to more data than usual and raise their autocitation rate in the text to defend their point of view.

The above advice should of course not be taken seriously as such. It is simply a summary of our results.

Finally, we give a few suggestions for possible follow-up studies. We did not study systematically the age distribution of the cited references, and how it varies with time in the different fields (we are thankful to the referee for pointing this out to us). Such distributions deserve to be determined, as they are indicative of the long- and short-term dynamics of the various fields. Another interesting study to be undertaken is to understand why some fields, like the interstellar medium, seem to generate more references to other fields than to its own, whether this is an artefact of the classification system, or a true effect.

Acknowledgements. Gérard de Vaucouleurs certainly did not expect that his papers would be used in this way when he handed a set of reprints to one of us many years ago, nor would he have approved. But this study was done with due respect to his memory, and in praise of his research and teaching.

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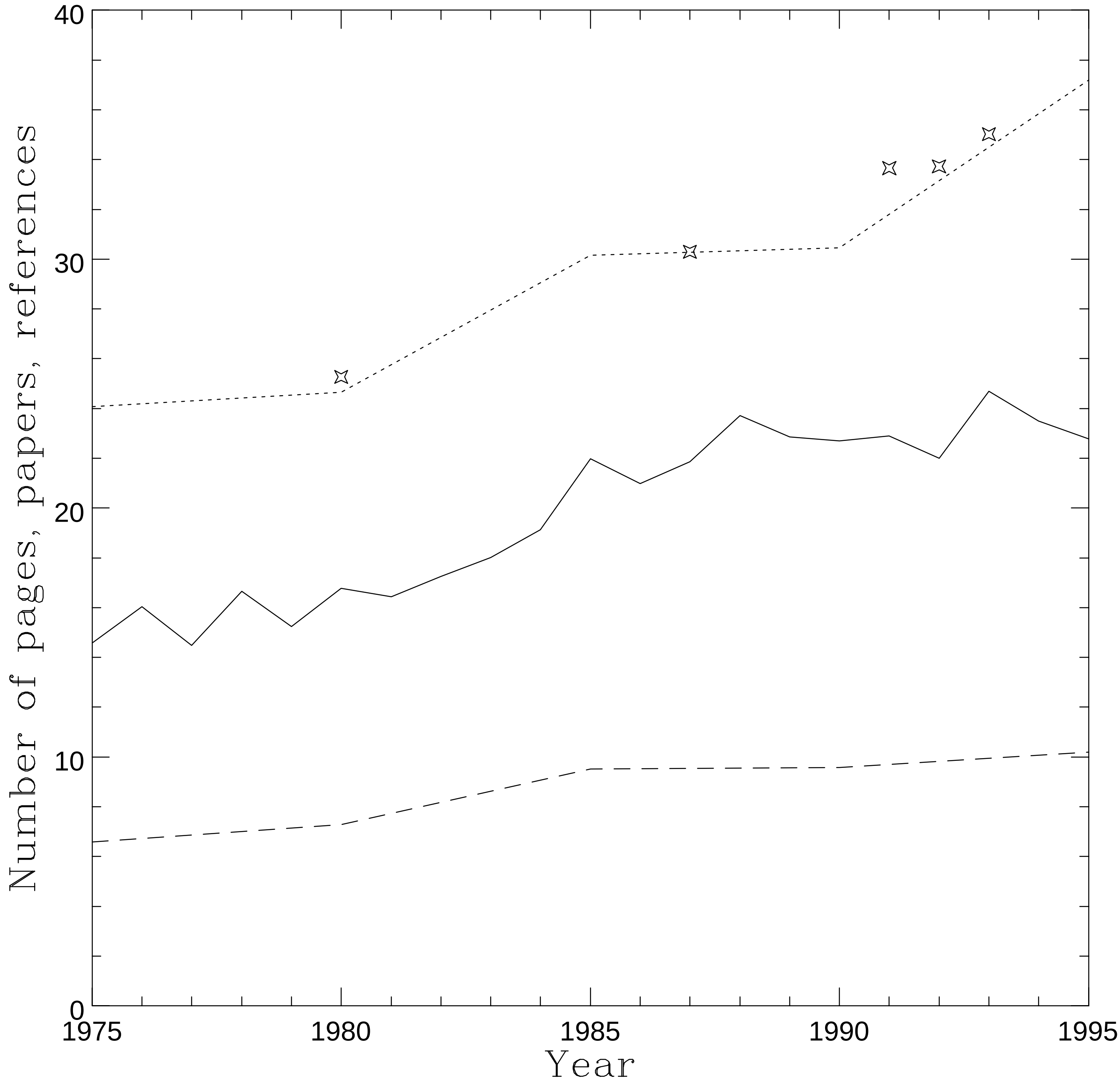

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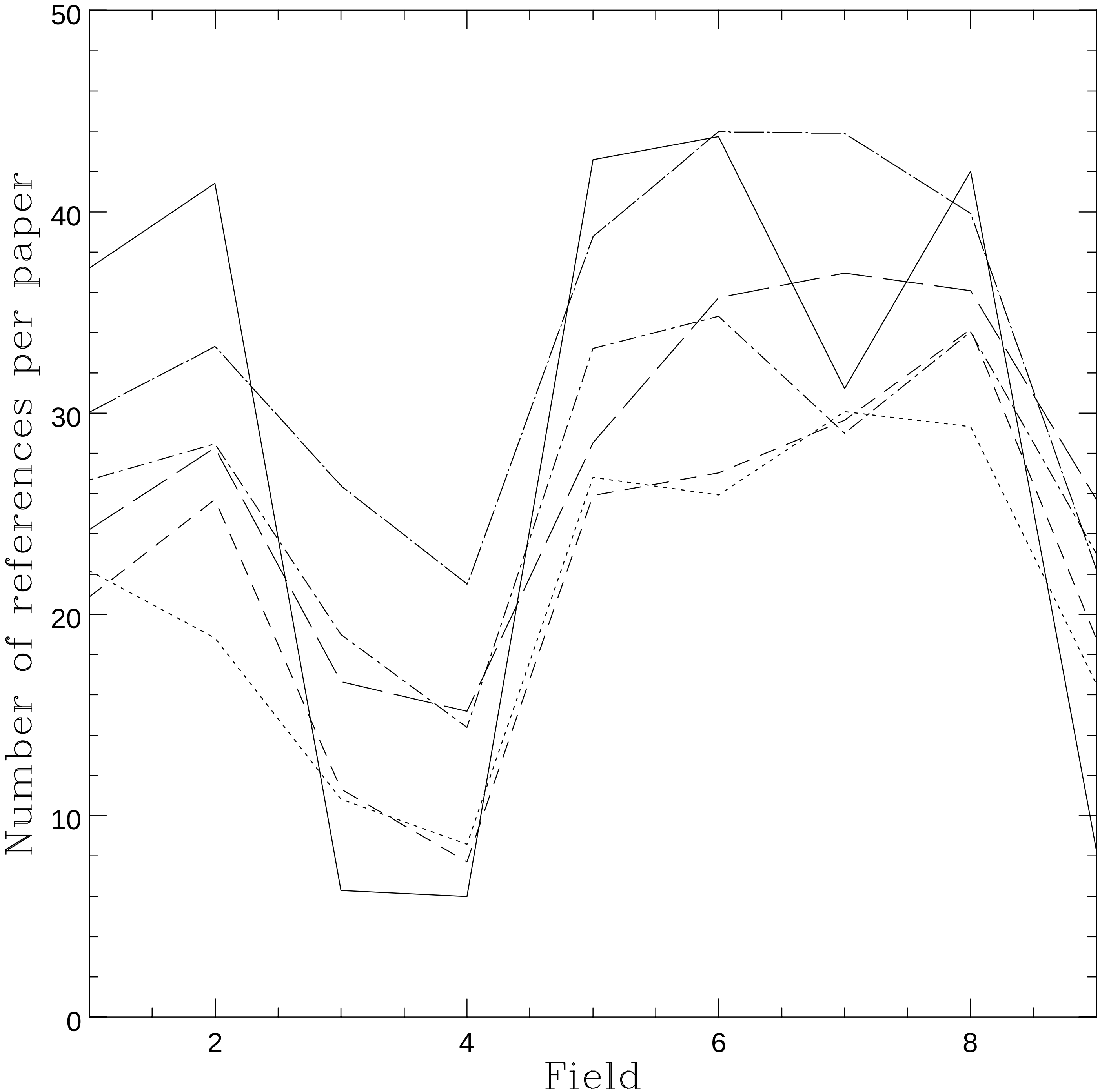

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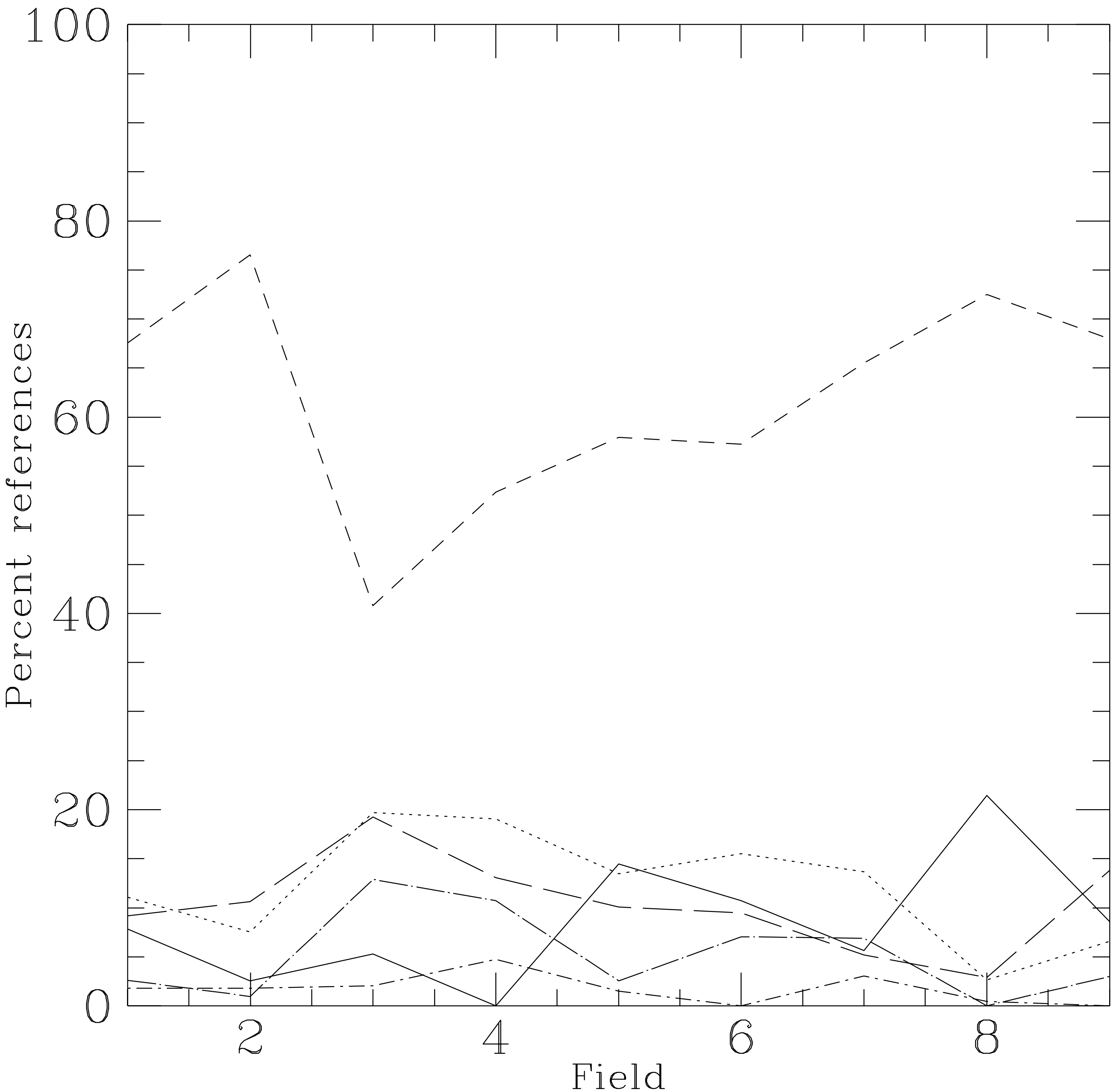

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